SPECIAL FEATURES OF USING N_2O FOR HEATING OF THE TEST GAS IN A HOT-SHOT WIND TUNNEL

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1. The study of heat and mass supply in gas-dynamics models with combustion involves the necessity of modeling not only aerodynamic criteria of similarity (M, Re, St, etc.) but also natural values of stagnation pressures and temperatures, since the conditions of self-ignition of the fuel, heat release in time and space, and chemical reaction rate depend significantly on P_0 and T_0 [1].

These or similar conditions can be obtained in short-duration facilities, in particular, hot-shot wind tunnels [2].

Figure 1,*a* shows the range of stagnation parameters P_0 and T_0 simulated in the IT-302M wind tunnel as functions of the initial pressure P_{0in} and specific energy with allowance for the actual efficiency of the power system. Figure 1,*b* shows the range of stagnation parameters required to study supersonic combustion for $M_{in}=6 \div 11$ and dynamic pressures $q=(0.2 \div 0.85)$ bar. For these dynamic pressures, the stagnation pressure reaches tens and hundreds of bars, and the temperature varies from 1500 K to $4000 \div 5000$ K and higher.

To model flight conditions (P_0, T_0) within the range $M_{in}=5 \div 7$, IT-302M has operating regimes with a throttling chamber (Fig. 2). In this case, with a plenum chamber volume of 7.5 liters, it is possible to obtain the running time equal to 80-100 ms for comparatively large nozzles ($D_n=200 \div 340$) mm.

Further extension of region (a), at least, to stagnation temperatures $T_0 \approx$ (3000-4000) K and pressures of $\sim(500 \div 1000)$ bar is possible only by increasing energy spent on test-gas heating. It is seen from Fig. 1 that the specific energy should reach ~ 300 kJ/dm^3.

The method of increasing the energy input into the wind tunnel, which is most suitable and available at the moment, is the use of alternative sources of energy, in particular, chemical energy, as an additional source of heat.

2. For these purposes, one can use the exothermic reaction of decomposition of nitrous oxide N_2O. The first studies in this field, namely, decomposition of N_2O in a closed chamber with arc heating, were performed by Williams [3] in 1964. It was noted in that paper that the pressure in the case of 92% decomposition of N_2O was approximately three times higher than the pressure obtained by an arc discharge only, and a mixture similar to air in composition and properties was obtained by adding nitrogen.

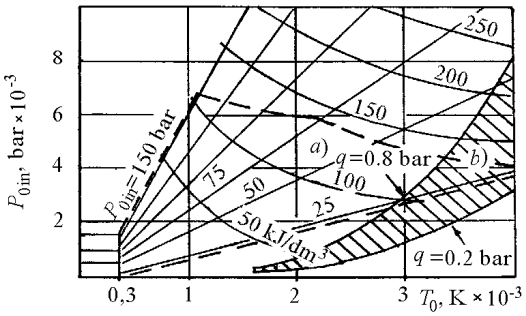

Fig. 1

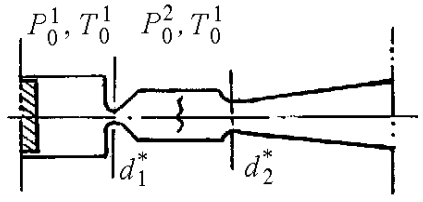

Fig. 2

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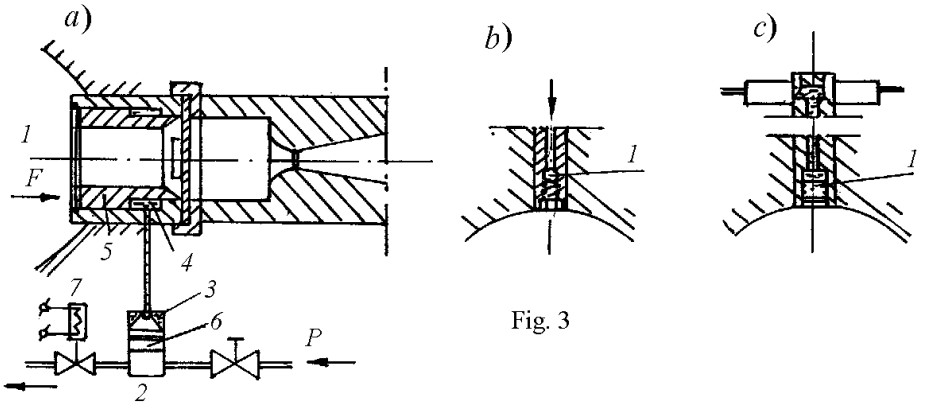

Fig. 3

Despite a comparative simplicity of these studies (the experiments were conducted in a closed volume), the use of nitrous oxide presents some problems under actual conditions with air used as the main test gas.

The first problem is the presence of a diaphragm broken by a discharge of a capacitor with increasing pressure in the plenum chamber. Experiments with N_2O inevitably fail if such a diaphragm is used, since the mass flow rate of the gas during diaphragm destruction decreases the temperature and terminates the reaction.

The second problem is the presence of channels of small volume in the body of the plenum chamber, namely, channels for filling the chamber by a compressed gas, for pressure measurements (P_0 (t)) at two or three points of the chamber, etc. The first experiments showed that the use of N_2O in the current construction of the plenum chamber led not only to premature destruction of the diaphragm but also to detonation of nitrous oxide in the channels. The main devices to be destroyed were the pressure gauges of the valve.

These specific features of N_2O decomposition necessitated upgrading of some elements of the IT-302M chamber, in particular, development of a controlled diaphragm capable of sustaining high pressures (up to 1000 bar) and modification of the construction of channels for filling the plenum chamber and pressure measurements.

Figure 3,*a* shows a sketch of the diaphragm unit with controlled disruption of the diaphragm, which was used in the second test series with N_2O. The modifications in the pipeline and pressure gauges (P_0 (t)) are shown in Fig. 3,*b*.

The diaphragm unit operated in the following sequence. Prior to filling the plenum chamber *1* by a compressed gas (or a mixture of gases), pressure was established in device *2*.

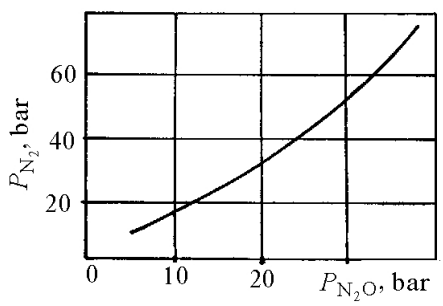

Fig. 4

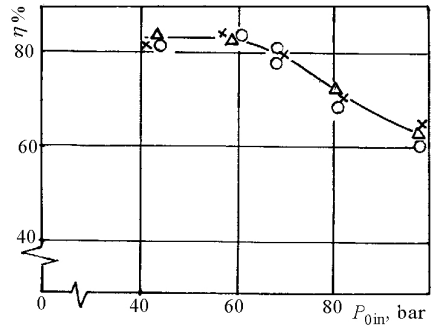

Fig. 5

Moved by this pressure, a two-step piston expulsed liquid *3* to tank *4*. A circular plunger (knife) *5* was shifted to the left and moved away from the diaphragm. After displacement of the liquid, piston *6* sealed the channel and did not allow plunger *5* to move to the right as the pressure in the plenum chamber increases up to 1000 bar.

Approximately 10-30 ms after the capacitor discharge and beginning of the N_2O decomposition reaction, electromagnetic valve *7* received a command to release the gas pressure from device *2* into the atmosphere. Under the action of the force from the plenum chamber on plunger *5*, the latter was shifted to the left and cut diaphragm *8*, which was 3 mm thick, over its incomplete perimeter.

The plenum chamber was filled by a mixture of gases through a reverse valve *1* (Fig. 3,*b*) mounted directly at the wall of the internal volume. When the plenum chamber was filled, it was additionally closed by a plug with an orifice. For reliable measurement of pressure with N_2O used, the channel connecting the internal volume of the chamber and the pressure gauge was filled by a liquid. The pressure was transferred through a light piston *1* of diameter of 1 cm, which was mounted at the channel boundary on the side of the chamber volume (Fig. 3,*c*).

3. Nitrous oxide decomposition proceeds with heat release (the thermal effect of the reaction is H_{N_2O}=1.863 MJ/kg)

$$2N_2O \rightarrow 2N_2+O_2.$$

It begins at 500 °C and is completed at 900^0C [4]. Therefore, the mixture of gases containing nitrous oxide should be preheated to an intermediate temperature T_{pre}=1000 ÷ 1200 K. A discharge of the IT-302M capacitor (charge voltage of 3 kV) was used for this purpose.

Almost instantaneous decomposition of N_2O near the arc results in release of additional energy in the IT-302M plenum chamber. Simultaneously, heat transfer to the ambient gas with a lower temperature begins. If the reaction rate if higher than the gas-temperature growth rate, then a complete, almost instantaneous reaction occurs. The completeness of the reaction is proportional to the initial partial pressure of N_2O and inversely proportional to the diffusion velocity of the gas being injected [3]. An incomplete reaction yields N_2O and NO, which is undesirable because of both heat losses and contamination of the test gas.

Figure 4 shows the pressure of nitrogen refilling versus the pressure of N_2O for T=293 K. If this relationship is satisfied, the reaction should produce a mixture consisting of 78% of N_2 and 22% of O_2.

To determine the completeness of N_2O decomposition, one has to know the efficiency of the arc heater of IT-302M, in other words, which part of heat stored in the capacitor is spent on test-gas heating. The charge energy of the capacitor was chosen to 528.3 kJ, which corresponded to 44% of the maximum energy stored.

The efficiency of the arc was determined when nitrogen was used as a test gas. The initial pressure of nitrogen in the plenum chamber $P_{in.eq}$ was determined under the assumption that the increase in the number of molecules due to N_2O decomposition would increase the initial pressure in the plenum chamber:

$$P_{ineq}(N_2) = \frac{P_{N_2O}}{2} \cdot 3 - \left(P_{mixture} - P_{N_2O}\right)$$

Variation of the arc efficiency η is plotted in Fig. 5 as a function of the initial pressure.

4. Experiments with nitrous oxide were performed for the following fixed pressures: P_{N_2O}=20, 25, 35, and 40 bar. The pressures for injection of additional nitrogen were taken from Fig. 4.

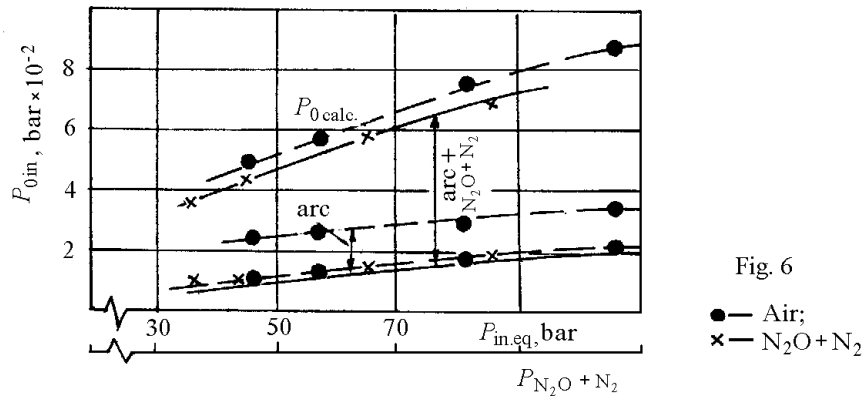

Fig. 6

Figure 6 shows the results of experiments with nitrous oxide N_2O, which are represented as the dependence $P_{N_2O,arc} = f(P_{N_2O}, P_{in.eq})$.

There is some disagreement between the numerical and experimental data obtained with combined heating of the mixture (arc + chemical energy). Nevertheless, taking into account that the level of heat losses to the discharge-chamber walls may reach (5-7)% during the delay time (~30 ms), this disagreement can be minimized by a proper correction.

5. The results of this work, namely, the use of the exothermic reaction of N_2O decomposition as an additional source of heat in the hot-shot wind tunnel, may be summarized as follows:

- some elements of the plenum chamber were modified, which allowed for investigations with N_2O in the operation regime of the hot–shot wind tunnel;
- the construction of a controlled diaphragm for ~ 1000 bar was developed;
- safety problems of tests with N_2O were solved;
- preliminary results on the efficiency of using N_2O in short–duration facilities were obtained.

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